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# WASTE DISPOSAL ASPECTS OF A NUCLEAR-WEAPON ACCIDENT


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NOVEMBER 1966

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# WASTE DISPOSAL ASPECTS OF A NUCLEAR-WEAPON ACCIDENT

Richard F. Smale
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Project 1N022601A089, Subtask 04-01

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US ARMY
NUCLEAR DEFENSE LABORATORY
Edgewood Arsenal, Maryland

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## ABSTRACT


Procedures for decontamination, collection, packaging, transportation and ultimate disposal of the large quantities of radioactive waste generated as a result of a nuclear-weapon accident are presented. Plutonium hazard and dispersion, previous research on nuclear-weapon accident hazards, as well as acceptable levels of contamination are reviewed and discussed. From Test Group 57 and Roller Coaster data, the extent of the significantly contaminated area was estimated to be between 0.1 and 0.5 $mi^2$.

Types of waste generated and methods of collecting, packaging, and transporting are presented for rural, industrial, suburban, and airfield areas. Only first approximations of economic costs are made for reclamation of each type of area. Social and legal costs are not estimated. The equipment for cleanup available to the Army through organic units and through Government agencies is reviewed.

It is concluded that, while the Army theoretically has sufficient resources to conduct a cleanup of an accident site, further study is needed to determine preplanned procedures, optimum utilization of available equipment, and expedient packaging procedures.


## FOREWORD

This work was authorized under Army Service Project 1N022601A089, Subtask 04-01 "Radioactive Waste Disposal Techniques," and was conducted during calendar year 1965.

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WASTE DISPOSAL ASPECTS OF
A NUCLEAR-WEAPON ACCIDENT

# 1. INTRODUCTION

## 1.1 Objectives.

The objectives of this study are to estimate the quantity of bulk radioactive waste generated as a result of a nuclear-weapon accident, to survey the current Army capability to package and dispose of such waste, and to give general guidance and recommendations of procedures for collecting, packaging, transporting, and disposing of such waste. It is not the objective of this study to present a minutely detailed and absolutely precise economic and logistical study. Where economic costs and logistical factors are given, they are only a first approximation and are given purely as examples.

## 1.2 Justification and Requirements.

Present Army policy is unclear as to procedures that should be used for handling, packaging and disposing of the large quantity of waste generated as a result of a nuclear-weapon accident. Public and legal aspects of an accident of this nature may require disposal of quantities of waste greater than is medically necessary. Effective and economical decontamination and disposition can be facilitated by proper preplanning and guidance.

## 1.3 Background.

1.3.1 Accident Hazard and Research. The storage and movement of nuclear weapons have always been a special concern to safety experts. Even though the number of accidents involving nuclear weapons has been extraordinarily low, the continuing movement of such items through the normal logistical chain concedes the possibility, however remote, that a nuclear weapon either in storage or in transport, will be involved in a serious accident. In order to properly understand the scope of this study, it is necessary to summarize the hazards associated with nuclear-weapon accidents. More complete and detailed information may be obtained from the many excellent publications in this field (References 1 through 4).

The two most hazardous materials in a nuclear weapon are the high-explosive component and the nuclear material. As a result of a serious accident the high-explosive component may detonate high order (i.e. completely), detonate low order, burn, or be widely scattered. In any of these cases, and for the purposes of this study, it is assumed that prompt and effective action by Explosive Ordnance Disposal and other safety teams will quickly neutralize the high-explosive hazard. By the time land reclamation and waste disposal procedures are initiated, only the nuclear material will be considered a long-term hazard.

Plutonium and uranium contaminations are the long-term radiological hazards of a nuclear-weapon accident. While uranium and plutonium contaminations are radiologically similar, uranium possesses a much lower specific activity. Consequently, measures and procedures sufficient to contain and dispose of plutonium will be more than adequate to deal with any uranium present.

Plutonium, a heavy metal similar in appearance to stainless steel, oxidizes easily and rapidly to take on a characteristic brownish-black appearance. Small filings are pyrophoric. If associated with a fire or an explosive, plutonium can easily be oxidized and pulverized into very minute particles that can cause serious contamination over a large area.

Plutonium is an alpha emitter. However, because of spontaneous fission and the fact the decay series includes isotopes that are beta and gamma emitters, beta-gamma radiation will always be present whenever plutonium is found in any quantity. When the plutonium is dispersed over a wide area, the beta-gamma radiation will be almost imperceptible (Reference 3).

As an alpha emitter, plutonium represents a radiological problem only when it gains entrance into the body. Radiological protection from plutonium consists simply in ensuring that it does not enter into the body. Body entry is through inhalation, ingestion, or breaks in the skin, with inhalation being the primary means. Since plutonium is highly insoluble in the gastro-intestinal tract (only 0.003 percent of that ingested will be absorbed in the bloodstream), and since deep wounds should not be a factor for the purposes of this study of long-term reclamation, hazards from ingestion and wound contamination are not considered. The primary hazard of plutonium is from inhalation of particles in the 1- to 10-$\mu$ range. Approximately 10 percent of the inhaled particles in this "optimum size" range are absorbed into the blood stream and will eventually be deposited in the bones. Plutonium deposited in the bones effectively remains for a lifetime and may cause long-term radiological damage.

With the increase in the number of plutonium-bearing weapons, present safety plans and hazards research are constantly being re-evaluated to minimize the possibilities of an accident and to better define the radiological hazards that would result if an accident were to occur. As early as 1955, Cowan and Kingsley (Reference 5) studied the hazard associated with an accident to a weapon containing plutonium and developed an idealized fallout pattern by use of parameters of specific meteorological conditions, particle size distribution, and cloud rise height.

The Los Alamos Scientific Laboratory performed the first field safety tests of pre-assembled plutonium-containing devices in the 56 Project at the Nevada Test Site (Reference 6). Although these were primarily safety tests, close-in alpha contamination studies were conducted and some contamination levels were documented; no fallout contours were delineated. Harris (Reference 7) made a comprehensive analysis, based partly on this data, of the acute and chronic radiological hazards and developed resuspension factors and acceptable permissible surface levels. The area of risk, the hazards within this area, and brief notes on decontamination techniques were also presented. Translation and extrapolation of the admittedly sparse data from Project 56 into shipping and storage safety criteria would have led to overly restrictive regulations, thus severely limiting the nation's response posture.

A more definitive evaluation of the plutonium contamination problem was required and was met by Test Group 57 of Operation Plumbbob in 1957 (Reference 8). This experiment involved a one-point detonation of a warhead for the sole purpose of evaluating all aspects of the plutonium hazard. This evaluation included (1) estimation of the extent of contamination, (2) biomedical evaluation, (3) decontamination effort, and (4) determination of resuspension factors. The decontamination effort (Reference 9) was large-scale and all practicable methods of decontamination were attempted and documented as to efficiency. This was the first documented large-area plutonium decontamination effort, and the results have since been used as standards for decontamination efficiencies in field and technical manuals (References 2, 3, 4, and 10).

The Test Group 57 Project remained the only large-scale field test of plutonium dispersal in a nuclear-weapon accident situation until the Roller Coaster Series in 1963. This later operation, conducted with joint US/UK participation, was a logical outgrowth of the 56 and 57 Projects and was designed (1) to investigate the biological hazard of plutonium scattered by non-nuclear explosions, (2) to evaluate the effectiveness of earth-covered storage structures in reducing the radiological hazard, and (3) to improve the forecast of the magnitude of the radiological exposure likely from a given accident situation. The series consisted of four separate events, each extensively documented for plutonium deposition, air concentration, and ground contamination (Reference 11). The bulk of data from the series has not been completely analyzed, but the plutonium deposition contours have been well documented for the various types of storage configurations.

Only two studies have extensively analyzed the expected costs and economics of a nuclear-weapon accident. For brevity, they will be denoted as the TORT Report (Reference 12) and the NAVWEPS Report (Reference 13). The TORT Report analyzed probabilities of incidents and accidents and developed expected overall recovery costs under various population density conditions. An acceptable level of ground contamination was arbitrarily assumed to be 100 $\mu g/m^2$ of plutonium. A one-pass, one-week decontamination effort was analyzed. Recovery costs were based on such factors as (1) cost of weapon, (2) cost of equipment, (3) cost of decontamination and replacement of personal property, (4) cost of interruption of services, and (5) overhead costs. Costs were then calculated for a railroad accident and an accident involving an airplane at an airfield. Decontamination costs for a single weapon railroad accident ranged from $20,000 per square mile for a sparsely populated rural area to $4.5 million per square mile for an area of population density greater than 2,500 persons per square mile. Analysis of decontaminating a typical airfield was $0.3 million per square mile. For these incidents, and for the one-pass decontamination effort, cost of land decontamination was based on cost of plowing under the topsoil.

The NAVWEPS Report estimated cleanup cost of a rural area at the value of the land plus the expense of plowing under the topsoil. The suburban, urban, and industrial decontamination cost is estimated from 10 to 50 percent of the total value of property improvements and personal property. With this criteria, costs range from $0.1 million per square mile for rural areas to $30 million per square mile for urban and industrial areas.

Study and comparison of these reports clearly indicate that estimates of costs for decontamination presupposes a minimum of radioactive waste. It was assumed that all open land would simply be plowed and that liquid runoff from washdowns would be allowed to leach into the ground or run into existing sewerage systems. No thought was given to the fact that, due to public apprehension and legal complications, a large amount of the land area may have to be physically removed, transported to another location, and disposed of as radioactive waste. The cost of a large scale removal operation of this type could be several orders of magnitude higher than that previously reported.

1.3.2 Plutonium Dispersion. In a nuclear-weapon accident, the plutonium may be spread either by detonation of the high explosive or by burning. If the high explosive in the weapon detonates high order (in one complete explosion) the plutonium will be pulverized, converted into an oxide fume of relatively fine particle size, become attached to larger particles, and taken up into a cloud to produce localized downwind fallout. If the high explosive in the weapon detonates low order (incomplete, or in a series of incomplete explosions), some of the plutonium will be pulverized and distributed as in a high order detonation and some will be scattered as debris. If the weapon is broken open and ignites, the plutonium will burn and the fine particulate oxide will be carried downwind in the smoke and dust. Plutonium that is not burned or vaporized will be locally scattered in sizable pieces.

The mechanics of plutonium dispersal during fires has been extensively reviewed by Mishima (Reference 14). He has shown that the particle-size distribution will vary widely with prior treatment, fire conditions, and physical shape. In general, it is assumed for conservative purposes that the oxide will be finely divided in the particulate-size range that will cause the greatest inhalation hazard.

In either case, the contaminated material is transported into a cloud, carried downwind, and deposited. The exact cloud distribution is dependent on particle size, cloud height, and specific meteorological parameters. The idealized cigar-shaped fallout pattern will not be followed in all cases because of the high percentage of particles that are too small to obey Stokes' Law, and their deposition is governed by local air turbulences, eddy currents, and terrain factors (Reference 7). These parameters will be unique to each situation so that it is impossible to construct a mathematical fallout pattern applicable to all accidents.

1.3.3 Acceptable Levels of Contamination. Once the cloud has passed and the plutonium is deposited on the ground, no external radiological hazard exists; if the plutonium-bearing particles are resuspended and subsequently inhaled, the chronic hazard would appear. An estimate of the chronic inhalation hazard can be made by defining a resuspension factor as

$$RF = \frac{AC}{GC} , \qquad (1.1)$$

where RF = Resuspension Factor in units of $m^{-1}$,
AC = Airborne Concentration,
and GC = Ground Concentration.

The airborne concentration is measured in units of micrograms per cubic meter ($\mu g/m^3$) or microcuries per cubic meter ($\mu c/m^3$). The ground concentration is measured in units of micrograms per square meter ($\mu g/m^2$) or microcuries per square meter ($\mu c/m^2$). The resuspension factor is then calculated in units of inverse meters ($m^{-1}$) and provides a linear relationship between the ground deposition and the chronic airborne hazard.

Mishima (Reference 14) tabulated values of variously reported resuspension factors ranging from $10^{-2}$ $m^{-1}$ (resuspension of a finely divided material from a newly painted concrete floor due to air and mechanical motion) to $10^{-13}$ $m^{-1}$ (resuspension of aged plutonium particulate matter from desert soil by natural turbulence). Realistic values range from $7 \times 10^{-5}$ $m^{-1}$ (Nevada vehicular traffic) to $7 \times 10^{-7}$ $m^{-1}$ (isolated area). Because the airborne hazard is directly proportional to the resuspension factor, any change or uncertainty in the resuspension has a direct bearing on the acceptable level of ground contamination.

In a typical field situation, the estimate of the resuspension factor will be uncertain by at least a factor of 10. This uncertainty is due to varying atmospheric conditions, different types of soil, different mechanics of deposition, and different kinds of movement within the area.

For the purpose of this report, the minimum acceptable level of contamination for a weapon accident will be taken as 100 $\mu g/m^2$ (6.4 $\mu c/m^2$). This value is in agreement with some authors (References 7 and 12) and in disagreement with others (Reference 13); it is convenient because most field tests have generally delineated the 1,10, and 100 $\mu g/m^2$ contours and, in the absence of detailed knowledge of resuspension factors, the use of 100 $\mu g/m^2$ as an acceptable limit will probably be within the limits of error or uncertainty. As an added precaution, the area enclosed by the 10 $\mu g/m^2$ contour should also be investigated to determine the feasibility of protective measures, such as fixation.

1.3.4 Probable Areas Involved. It has generally been accepted that for a given energy release and constant meteorological and terrain conditions, the area enclosed by any isocontamination line will be directly proportional to the amount of plutonium in the weapon and inversely proportional to the contamination intensity. This relationship may ideally be stated by

$$A = K \frac{P}{I}, \tag{1.2}$$

where

A is the affected area in square miles,

I is the contamination boundary in $\mu g/m^2$,

P is the mass of the plutonium in kilograms,

and K is a constant of proportionality.

Assume that both K and P (and therefore PK) are constant for any single accident situation; the relationships between areas bounded by isocontamination contours are ideally given by

$$A_1 I_1 = A_2 I_2, \tag{1.3}$$

where $A_1$, $A_2$ is the area bounded by any two isocontamination lines, $I_1$ and $I_2$.

Notice that as long as consistency is maintained, this relationship is independent of the units involved. Because of localized conditions and variations in tests, correlation of formulas to determine K has been difficult. Use of a standard constant for any accident situation is impossible; Roller Coaster data have shown that various types of covering will drastically alter the scavenging characteristics of the local environment and directly affect the extent of the fallout area.

On April 24, 1957, Operation Plumbbob Test Group 57 conducted a one-point detonation of a plutonium-bearing device for the purposes of studying the plutonium hazards from accidents involving weapons of this type. From D-day to D+2 days, approximately 1400 broom-finished concrete blocks measuring 10- by 10- by 1-inches, arrayed around the shot location, were surveyed by field alpha meters. The meter readings were converted to plutonium concentrations by a 1/3 roughness factor for self-absorption (Reference 15).

The alpha-survey results are shown in Figure 1.1. Areas within the isocontamination contours, the product of the area, and the maximum contamination are shown in Table 1.1.

TABLE 1.1 AREAS INCLOSED BY VARIOUS ISOCONTAMINATION CONTOURS, TEST GROUP 57, PROGRAM 74

| Contour, I | Area, A | AI |
|---|---|---|
| $\mu g/m^2$ | $mi^2$ | |
| 3500 | 0.003 | 10.5 |
| 1000 | 0.03 | 30 |
| 100 | 0.43 | 43 |
| 10 | 2.5 | 25 |

As can be seen from Figure 1.1, the areas are roughly elliptical in shape and were dependent on local wind conditions. Examination of Table 1.1 shows an AI product variation of a factor of 4.

In May 1963, the Roller Coaster series of one-point detonations was conducted at the Tonapah Test Range (1) to study the biological hazard of plutonium scattered by nonnuclear explosives, (2) to evaluate the effectiveness of earth-covered storage structures in reducing the radiological hazard produced by a detonation within the structure, and (3) to improve mathematical cloud models. Four shots, named Double Tracks and Clean Slate Nos. 1, 2, and 3, were fired according to the following conditions (Reference 11).

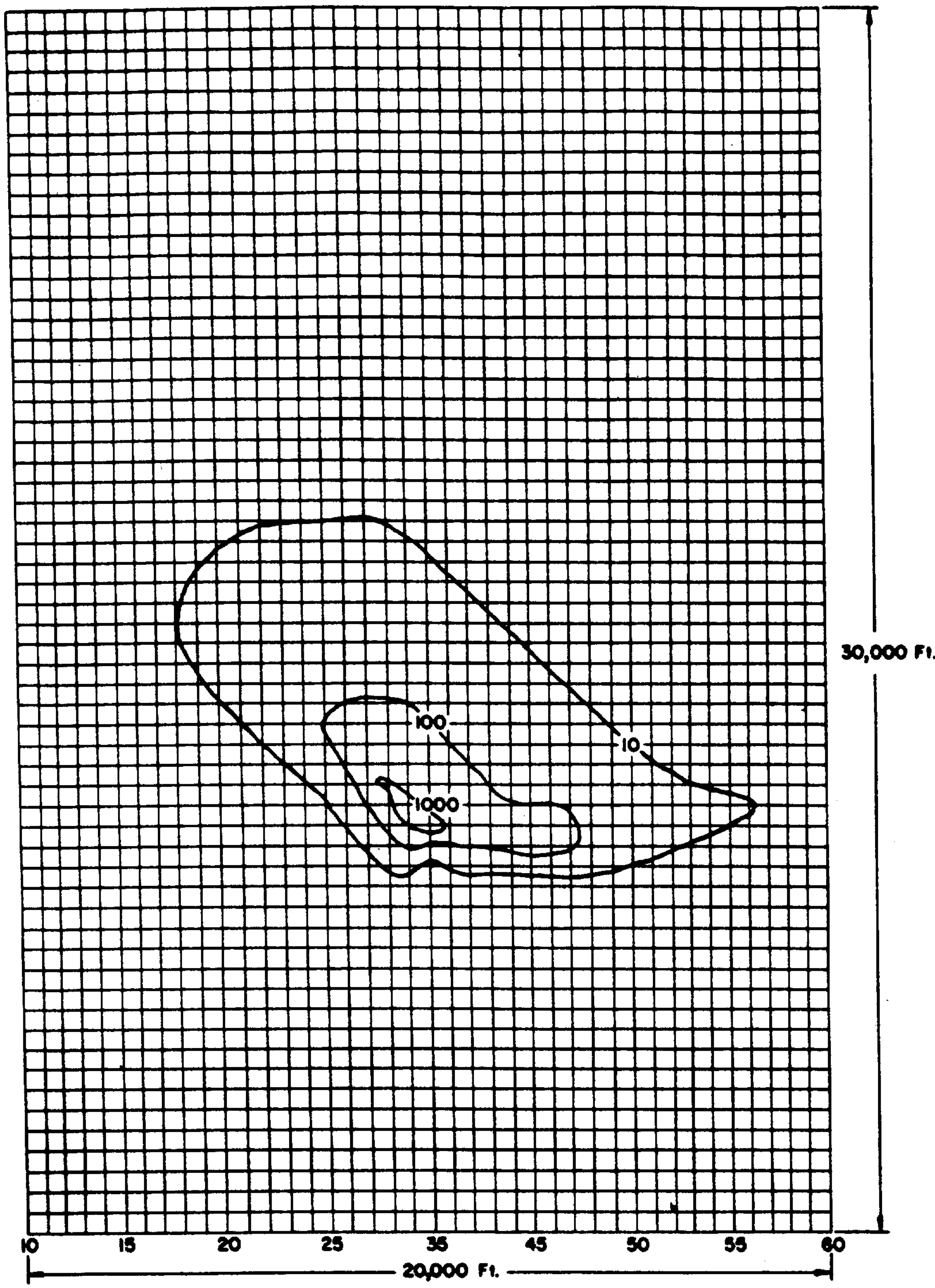


Figure 1.1 Contours of TG-57 deposition, by alpha survey.

Double Tracks. One device, normally containing plutonium and Oralloy, was contained in an aluminum case and made suitable for one-point detonation. All Oralloy was removed and replaced with Depletalloy of similar mass and configuration. The device was detonated 1 foot above a steel-faced concrete surface.

Clean Slate 1. Nine devices, one containing plutonium, and the others simply HE spheres containing Depletalloy, were detonated in sequence in an open storage configuration on a concrete pad.

Clean Slate 2. One plutonium-containing device was one-point detonated in a standard type igloo covered by 2 feet of earth. Eighteen other devices, with the plutonium replaced by Depletalloy, were stored in the same igloo and detonated in sequence.

Clean Slate 3. This shot was similar in all respects to Clean Slate 2 with the exception that the igloo was covered by 8 feet of earth.

After each shot, an alpha survey was conducted with survey meters and deposition contours were plotted. Representative displays are shown in Figures 1.2, 1.3, 1.4, and 1.5. The areas of selected isocontamination contours and the AI products are given in Table 1.2.

Comparisons of Figures 1.1 through 1.5 and Tables 1.1 and 1.2 show a great deal of variation, not only between the Test Group 57 and Roller Coaster data but also among the various Roller Coaster shots. The Test Group 57 data give areas different from the Roller Coaster data by factors of 3 to 10 greater at 10 $\mu g/m^2$ and factors of 4 to 400 greater at 100 $\mu g/m^2$. These differences can be attributed to local parameters, such as configuration of device, type of overburden or protective covering, scavenging by associated materials, and local weather conditions. It is obvious that theoretical cloud models, while useful, will not be capable of predicting the contaminated areas. The best that can be said is that the field studies show that the maximum hazard area requiring reclamation (100 $\mu g/m^2$) is 0.5 $mi^2$; it is also necessary to investigate areas up to 2.5 $mi^2$ (10 $\mu g/m^2$). The hazard area, however, could be only 0.001 to 0.1 $mi^2$.

1.3.5 Radiological Reclamation. Large-scale decontamination and reclamation procedures have been extensively analyzed and evaluated in the area of radiological recovery, that is, recovery from a large-scale radiological warfare attack or a nuclear-fallout situation. The military and Civil Defense studies of this problem are generally directed at minimizing the beta-gamma hazards but the techniques and procedures are equally applicable to plutonium decontamination.

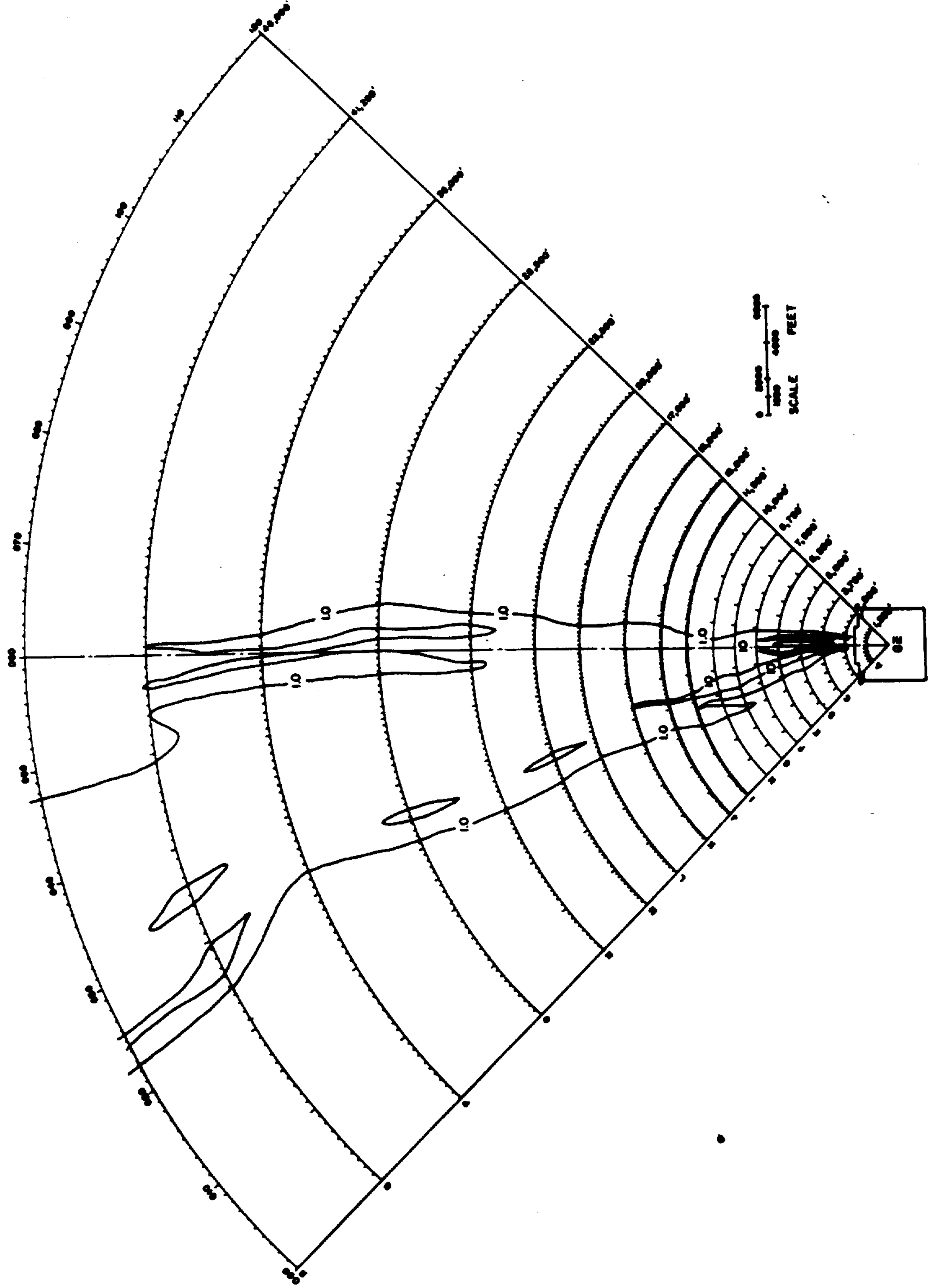


Figure 1.2 Contours of DOUBLE TRACKS deposition in $\mu g/m^2$, by alpha survey.

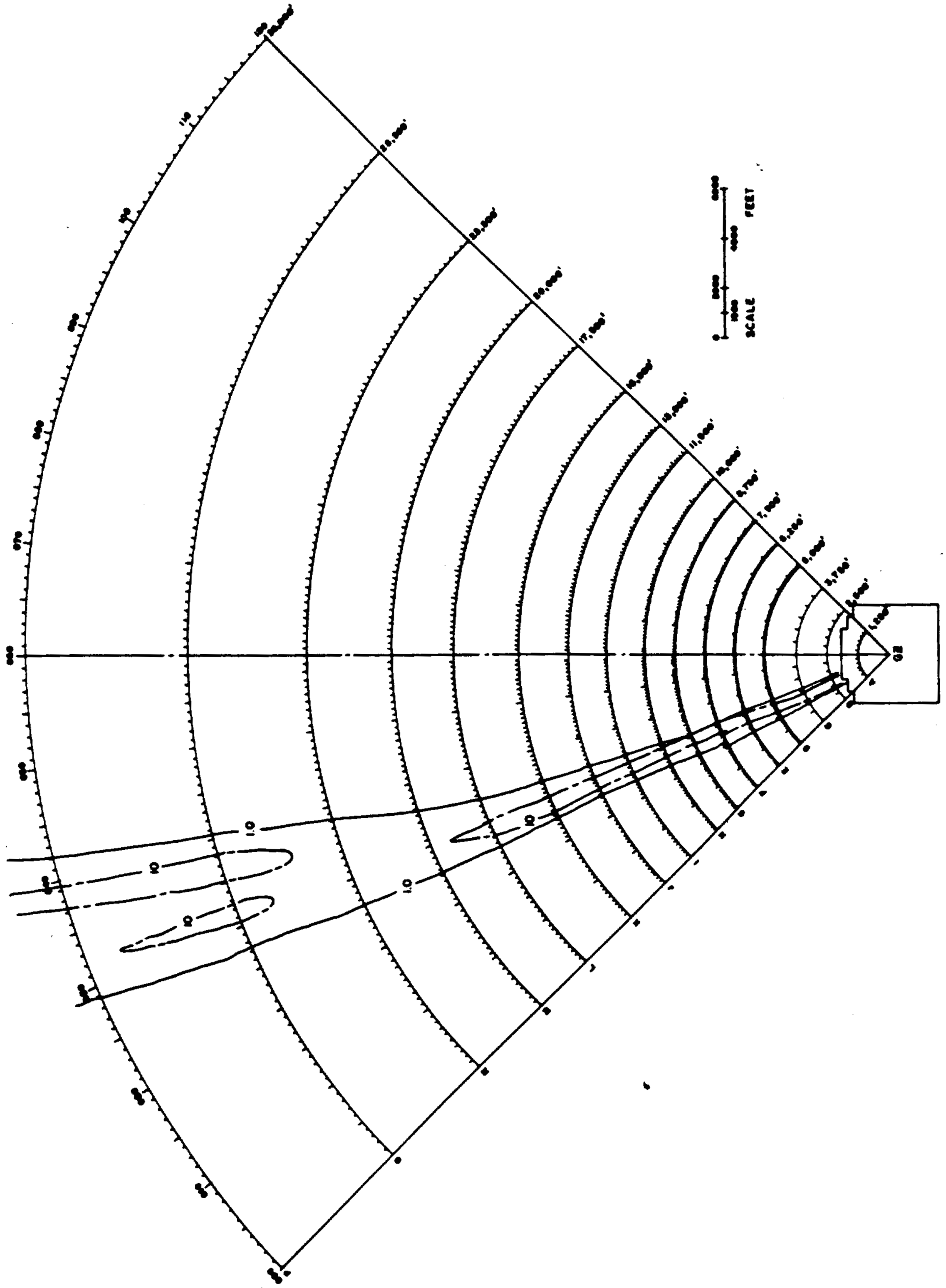


Figure 1.3 Contours of CLEAN SLATE No. 1 deposition in $\mu g/m^2$, by alpha survey.

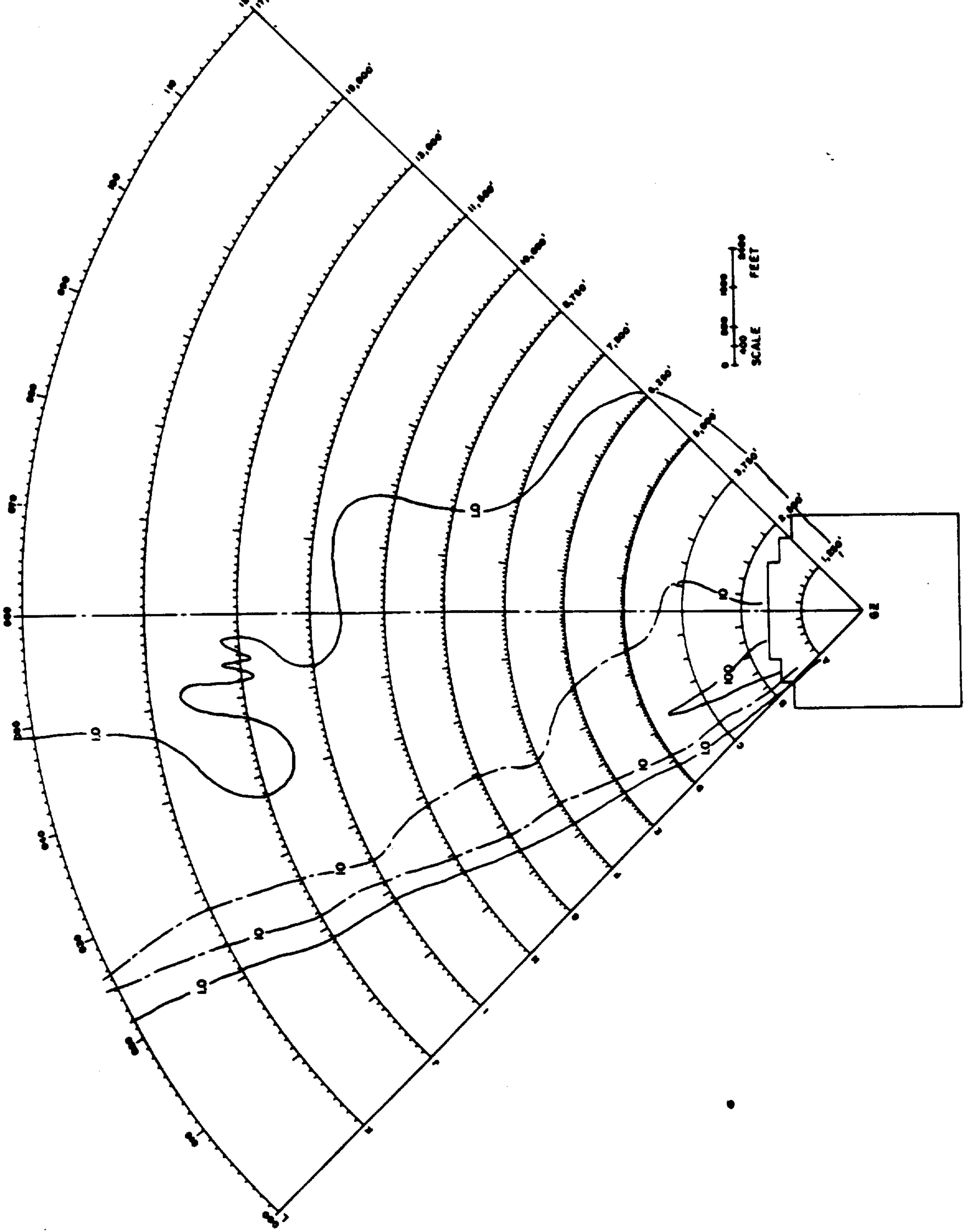

Figure 1.4 Contours of CLEAN SLATE No. 2 deposition in $\mu g/m^2$ alpha survey.

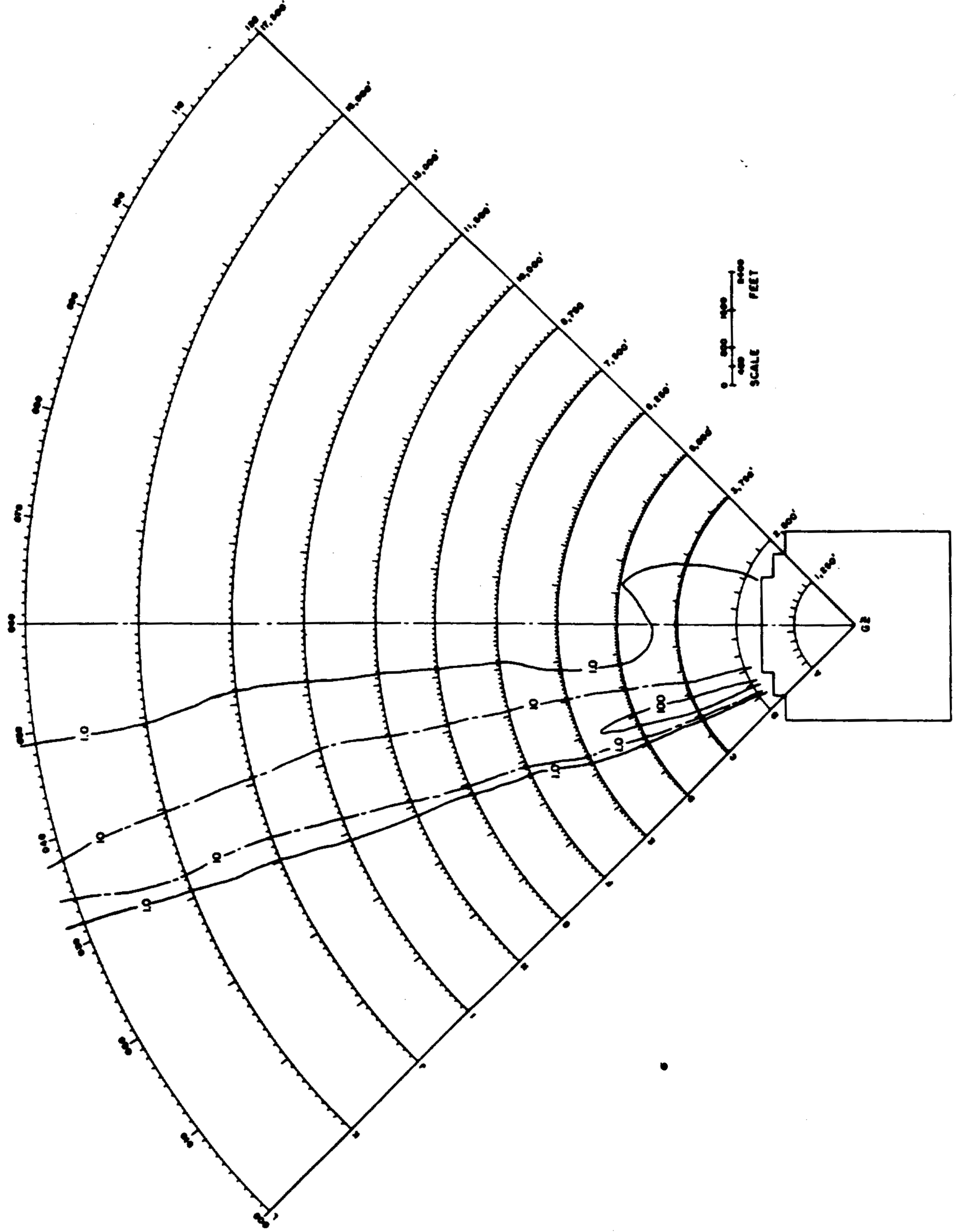

Figure 1.5 Contours of CLEAN SLATE No. 3 deposition in $\mu g/m^2$ by alpha survey.

TABLE 1.2 AREAS ENCLOSED BY VARIOUS ISOCONTAMINATION CONTOURS, ROLLER COASTER*

| Shot | Contour, I | Area, A | AI |
|---|---|---|---|
| | $\mu g/m^2$ | $mi^2$ | |
| Double Tracks | 1 | 15.1 | 15.1 |
| | 10 | 0.274 | 2.74 |
| | 100 | 0.001 | 0.1 |
| Clean Slate 1 | 1 | 3.1 | 3.1 |
| | 10 | 0.284 | 2.84 |
| | 100 | 0.003 | 0.3 |
| Clean Slate 2 | 1 | 3.6 | 3.6 |
| | 10 | 0.92 | 9.2 |
| | 100 | 0.10 | 10.0 |
| Clean Slate 3 | 1 | 1.85 | 1.85 |
| | 10 | 0.77 | 7.7 |
| | 100 | 0.054 | 5.4 |

*Reference 11.

In 1954, a detailed survey on the recovery of a major industrial complex from a radiological warfare attack was conducted by the Chemical Corps Chemical and Radiological Laboratories (Reference 16), a predecessor organization of this Laboratory. In this report, an arbitrary density of radiation per square mile was assumed and the gross amount and type of radioactive waste generated during the reclamation procedure was analyzed. Specific amounts of waste for various types of land usage were calculated; liquid waste was to be carried off in the sewerage system while solid waste was to be hauled to a disposal site and buried by trench-fill procedures. A very detailed logistical analysis was made of each method of decontamination.

Reclamation of large land areas from radioactive fallout is well documented in TM 3-225, "Radiological Recovery of Fixed Military Installations" (Reference 17). This is the prime military guide and is complete in almost every detail. It includes stepwise mechanics of reclamation, rates of operation, effectiveness of the various methods of decontamination, and minor waste disposal aspects of the problem. Methods of reclamation that are documented include firehosing, motorized flushing, scrubbing, hot liquid cleaning, scraping soil with motorized scraper, motor grader or bulldozer, and filling. The manual also details the radiological safety procedures that must be followed, in particular the use of respirators and protective masks that must be worn to minimize the airborne hazard.

While both the CRL report and TM 3-225 are very detailed in the mechanics of reclamation of large areas, and the CRL Report outlines in minute detail waste disposal procedures, both are, to some extent, not applicable to the problem at hand. Reclamation after a nuclear or RW attack supposes an emergency wartime situation, domestic mobilization, and effective military or civil defense control of the area involved. These conditions will be absent where a peacetime weapon accident occurs on non-Government property. Although the military may have temporary control of the area, full mobilization of civilian resources will not be available. The emergency tolerances and relaxation of radiological safety precautions that might be attendant to extreme situations will not be present; reclamation work will have to proceed under the normal peacetime safety criteria and exposure limits. Such limits will appreciably reduce personnel and equipment work output and efficiency.

## 2. DECONTAMINATION AND DISPOSAL

### 2.1 General.

This section examines the various large-scale decontamination methods that may be used during reclamation of an accident site and estimates the magnitude of the waste generated during these operations. It should again be noted and emphasized that the volume of waste generated per unit area will be an order-of-magnitude estimate only; actual volumes will vary according to the type of terrain, type of equipment used, spillage, operator efficiencies, and numerous other variables.

For the purpose of this study, it is assumed that a maximum decontamination effort will be made; that is, all areas within the 100 $\mu g/m^2$ contour will be decontaminated to as low a level as possible. The area between the 100 $\mu g/m^2$ and 10 $\mu g/m^2$ contours may be fixed or decontaminated as the situation permits. Free land or open areas will be decontaminated by scraping off the first 3 inches of topsoil (98 to 100 percent efficient); hard-surface areas will be washed down with water or with water and detergent (96 to 100 percent efficient, Reference 3); trees and foliage will be collected and disposed of as solid waste. The volume of waste generated will be calculated per square mile of affected area; volumes for composite areas may be calculated by prorating the various areas involved.

## 2.2 Rural Areas.

2.2.1 Characteristics. Rural areas include farmland, open areas, woods, and highways or railroad rights-of-way bordering these areas. Such areas constitute a major portion of nuclear-weapon shipment routes and can be considered as a prime area for an accident in shipment. Soil and climate may vary from hot dry desert soil to moist swamps. Over 98 percent of rural area is open or free land in the sense that it is not paved or improved. All of the radioactive waste generated will be solid, the majority being soil, the rest being trees, foliage, and small items of personal property. Open land represents the easiest area to reclaim because it is easy to survey and control. It is ideally suited for operation of earthmoving equipment thus minimizing the number of personnel and risk of contamination. Since there will be relatively few habitable dwellings, the need for an emergency or short recovery time will be less and a more detailed and comprehensive reclamation effort can be planned.

2.2.2 Decontamination. Open areas may be reclaimed in a variety of ways: (1) fencing off the area and allowing the plutonium to become fixed by weathering, (2) fixing the plutonium with an oil spray, (3) plowing the topsoil, (4) actually scraping the topsoil, or (5) combinations of these methods. Only scraping the topsoil can be precisely called decontamination in the sense that it physically removes the radioactive material; the others merely reduce the resuspension factor to a point where there is no airborne hazard. Only two methods of decontamination, stripping the soil and plowing under, will be studied in detail. Plowing the soil under is a minimum type effort requiring the least amount of time, manpower, and cost. The logistical problems in scraping, collecting, and moving the topsoil are sufficient to rank this as a maximum effort.

As an order-of-magnitude calculation, scraping off 3 inches of topsoil will yield 258,000 $yd^3$ of soil per square mile of land worked. Addition of an estimated factor of 100 percent to compensate for soil loosening, uneven depths of cuts, spillage, foliage, underbrush, and debris will give an approximate total, exclusive of large trees or structures, of over 500,000 $yd^3$ per square mile of open land. Using an approximate rule of thumb of a soil density of dry loam (2000 $lb/yd^3$) gives an approximate weight of 500,000 tons of solid waste per square mile of open land area. An effort of this magnitude can be accomplished only by use of large earthmoving equipment such as tractors, dozers, scrapers, and graders. Such items are engineer equipment, and many manuals (References 18 through 22) are available to estimate the effectiveness and economic utilization of this equipment.

2.2.3 Collection and Packaging. Collection and packaging methods will vary in accordance with the total effort. If the decontamination effort is simply plowing under the open area, the total collection and packaging will be nearly zero. If the maximum effort of scraping the topsoil is attempted, it will be necessary to collect and package 500,000 $yd^3/mi^2$ of contaminated soil, and the collection and packaging efforts will be maximized.

At the accident site, the most efficient method of collection and packaging is by a motorized or towed scraper. After land clearing operations have been completed, the scraper removes the top 3 inches of soil by forcing the soil into the bucket body of the machine. When the body or pan is full, the scraper carries the soil to the railhead (or to the dump) and dumps the soil. With high-speed rubber tired scrapers, this method can be very rapid with the advantage of minimum handling and transfer. With an 18 cubic yard wheel-type scraper, rates can be as high as 100 $yd^3/h$ (References 18 and 19). The only disadvantage of this type of collection is that the unit must travel over the contaminated ground and must be monitored for contamination before leaving the accident area.

Another very efficient method is by grading the topsoil into windrows by either motorized graders or angledozers. The windrows are then cast into a hauler (dump truck, scraper, or dump wagon) by either a front-end loader or an elevating grader. Here again, the use of a grader puts part of the equipment on the contaminated soil but, since the grader does not have to leave the area, this problem is minimized. The hauling units can operate on the sections already scraped and thus minimize spreading the contamination. Major dust and resuspension problems are evident in either collection method and can be controlled by frequent and extensive water or oil spraying. The hauling equipment necessary to maintain efficient operations will again depend on the length of haul to the transfer point and the rate of speed of the hauling unit.

The packaging of the soil for shipment will be the most critical phase of the whole operation from an economic and radiological safety standpoint. Unless waivers or interpretations of ICC Regulations are favorable, the packaging restrictions will be so stringent that a large portion of the recovery cost will be needed to fabricate field expedients or construct shipping containers. If topsoil is hauled in open units such as dumps, wagons, and trucks, the load should be sprayed with a road oil spray or covered with canvas, metal, or plastic.

Standards for packaging of beta-gamma emitting material are well known but specific standards for low-activity, alpha-emitting waste are very vague. Packing and shielding regulations (49 CFR* 73.393) require an inside metal shipping container, ICC Spec 2R, for materials containing plutonium, and it is questionable as to whether railroad cars can meet the packaging exemptions listed in 49 CFR 73.392. If the entire rail car qualifies as a shipping container, the packaging can be done in a "Type LO" covered hopper car at an average of 70 $yd^3$ per hopper. This would require a total of 7100 hopper car loads per square mile of land contamination. Although it would be theoretically feasible to utilize the large fleet of Army box cars to haul the soil, radiological contamination control problems probably would be greater than any cost reduction that might result.

*Code of Federal Regulations.

Unless specific waivers are granted under 49 CFR 71.3 and 49 CFR 71.7, any type of shipment would have to conform to existing regulations or else be made under 49 CFR 73.7 (b), which states "Shipments of radioactive materials made by the Atomic Energy Commission or under its direction or supervision, which are escorted by personnel specially designated by the Atomic Energy Commission, are exempted from the regulations in parts 71 to 78."

Preclusion of bulk carload shipments would necessitate use of shipping containers. Fabrication of special shipping containers would be economically unfeasible; however, standard conex transporters* with a minimum of modification could be used adequately for bulk waste shipments. Properly loaded, sealed and braced, these containers can hold up to 10 $yd^3$ and seven can be loaded into a 50-foot flat car, 70 $yd^3$ per car, or 7100 carloads per square mile (50,000 total conex loads) of free land area processed. Loading of the soil into the conex can be accomplished at the accident site, the outside can be sealed and decontaminated prior to leaving the accident area, and the transportation to railhead and disposal site will be radiologically safer. Thus, the increased time and cost necessary to load the containers will be offset by a work-output increase resulting from reduced need for special clothing and protective equipment at all other points.

### 2.2.4 Transportation.

#### Motor

Unless the disposal site is within approximately 50 miles of the accident site, it is not feasible to transport the solid waste directly to the disposal site by overland transportation. An exception to this may occur when organic transportation units are used and direct costs are not levied against equipment usage and labor times. If transportation is by Government motor vehicle, an interpretation of ICC Regulations should be made to determine applicability of packaging requirements. If transportation is by open-top conveyances, the load should be fixed by oil spraying the top surface, or by attaching expedient covers of canvas, sheet metal, or plastic. The route should be carefully reviewed, patrolled, and continually surveyed for spillage. Because of the large number of units needed, the route should be used exclusively by the hauling units.

#### Rail

The fastest and most economical method of transportation is by rail. Using covered hoppers for bulk soil or flat cars for conex containers is an efficient method of transportation to the disposal site. Special routing of shipments at low traffic periods will have to be utilized for

*FSN 8115-271-7000 Box, Metal, Shipping, Reusable, Transporter, Steel Type 2, 295 cubic feet capacity, 8'-6" long, 6'-3" wide, 6'-10-1/2" high, cost $2,000.

safety considerations. Bulk shipping rates from the railroad companies can be contracted on the strength of point-to-point routing and unit train makeup.

2.2.5 Ultimate Disposal. If the waste were to be physically removed from the accident site, it is apparent that the selection of the ultimate disposal site would be paramount. Disposal at commercial sites would be too expensive ($20.00 per cubic yard plus $0.06 to $0.40 per ton-mile transportation). The most economical disposal site would be the accident site itself. The farther the disposal site is from the accident site, the more costly the transportation and radiological safety functions become. Precluding the accident site itself, the most desirable disposal area would be one under Government control, preferably a military installation. Such a disposal site should have the obvious advantages of good transportation facilities, large amounts of unused free land, and excellent control and security. Selection of such a site should be based upon the nearness of the installation to the accident, amount of free land, type of soil, and depth of the water table.

The only feasible method of disposing of waste soil is burial by the trench-fill method, which is commonly used in commercial refuse disposal. Side-by-side trenches 15 feet deep and 30 feet wide are excavated, by dragline or clamshell, as long as is necessary or convenient. The material to be disposed of is dumped into a trench and then covered by fresh soil from the adjacent trench excavation. A total trench length of 10,000 yards will be required to bury 500,000 $yd^3$ of waste; this total can be broken down into many series of parallel trenches convenient to the shape of the disposal area. Transportation by hopper cars will necessitate construction of expedient unloading trestles or offloading into local hauling units for transportation to the trench. If the transportation is done by conex containers, rail spurs can be constructed parallel to each set of trenches and the containers lifted off by crane, dumped, and repositioned back onto the flat car for decontamination and subsequent rotation back to the accident site. In either case, proper preplanning can minimize outside contamination of the hauling units.

When all the waste has been deposited and covered with fresh soil, the area is revegetated for fixation purposes and fenced off as a controlled area.

## 2.3 Industrial Areas.

2.3.1 Characteristics. Industrial areas are typified by a low percentage of free land. The improved areas will be about equally divided between paved areas and built up industrial structures. Use of the very large construction equipment will not be practicable due to the variety of structures. Much of the work will have to be done with smaller equipment or by hand labor with a corresponding decrease in work output per unit area and a consequent increase in cost.

Reclamation of an industrial area from a radiological warfare attack has been previously noted and extensively analyzed. Almost all procedures developed are applicable to a nuclear-weapon accident.

2.3.2 Decontamination. The paved areas should be decontaminated by vacuum cleaning the surface, by water hosing or motorized flushing. The structures are decontaminated by vacuum cleaning, hot-water lancing, or water hosing.

Vacuum sweeping presents the least problem. Reference 23 data indicate that available commercial sweepers can achieve high efficiencies and rates of operation with relatively little waste generation. The commercial sweeper can achieve realistic operating rates up to 67,000 $ft^2/h$ with high efficiency for containing dry particulates. With an operating factor of 60 percent, a total square mile of paved surface can be decontaminated in less than 700 equipment hours with surface dirt contained in the hopper being the only waste generated. The waste can then be bagged and sealed in relatively small shipping containers. This unit appears to be the fastest, safest, and most economical method of decontaminating paved areas.

For water hosing, large quantities of liquid waste will be generated. The criteria in TM 3-225 are used in Table 2.1 to summarize the amount of liquid waste that can be expected. All liquid methods, except the specialized hot-water cleaning, will generate over $20 \times 10^6$ $gal/mi^2$ of liquid, or nearly 1 $gal/ft^2$. At a normal specific volume of 0.134 $ft^3/gal$ this will be equal to $2.8 \times 10^6$ $ft^3$ or $1 \times 10^5$ $yd^3$.

TABLE 2.1 ESTIMATED LIQUID WASTE GENERATION DUE TO CLEANING OPERATIONS (REFERENCE 17)

| Type of Operation | Water Rate | Rate of Operation | Waste Generated | |
|---|---|---|---|---|
| | $10^3$ gal/h | $10^3$ $ft^2/h$ | $gal/ft^2$ | $10^6$ $gal/mi^2$ |
| Firehosing Areas | 6 | 7.5 | 0.8 | 22 |
| Firehosing Structures | 6 | 2 | 3 | 83 |
| Motorized Flushing | 48 | 35 | 1.37 | 38 |
| Firehose & Hand Scrub, Areas | 5 | 5 | 1 | 28 |
| Firehose & Hand Scrub, Structures | 5 | 2 | 2.5 | 70 |
| Hot Liquid Cleaning, Roofs | 12 | 2.5 | 0.48 | 13 |
| Hot Liquid Cleaning, Walls | 12 | 2 | 0.6 | 17 |

Decontamination of any unpaved areas will be handled in the same manner as those discussed in Section 2.2 Rural Areas, with the exception that smaller equipment must be used due to the congested areas.

2.3.3 Collection and Packaging. If the liquid waste is to be collected, packaged, and transported to a disposal site rather than being diluted into a sewerage system, volumes on the order of $10^7$ to $10^8$ gal/mi$^2$ will have to be collected and packaged. Volumes of this type present unique problems in spillage, drainage, and collection. All available drainage outlets must be blocked off and collection and transfer areas must be established. The liquid, presents a very minor resuspension hazard, can be easily pumped to a storage system, and transferred with few contamination problems. For these reasons, liquid waste will not require as detailed radiological precautions as solid waste.

Volumes of liquids as large as 10 million to 100 million gallons require a multitude of high-capacity containers such as railroad tank cars, although transportation from the collection site to a railhead may be done by 5,000-gallon M131A2 semitrailers. The capacity of a standard USAX railroad tank car is 10,000 gallons; therefore, a volume of liquid waste between $10^7$ and $10^8$ gal/mi$^2$ would be from 1,000 to 10,000 tank-car loads.

The amount of liquid to be collected and packaged may be materially reduced by processing the liquid at the accident site, either by a chemical extraction method or by a simple distillation process. USANDL has investigated the feasibility of a semiportable wiped-film concentrator. With larger capacity units of this type, the liquid waste can be separated into a small volume of radioactive sludge and a large volume of noncontaminated water. The water can then be dumped or reused to washdown other contaminated structures, and the amount of liquid waste to be packaged can be materially reduced.

2.3.4 Transportation. As noted in the previous section, if the liquid has to be transported to a disposal site, the only feasible method of transportation is by 5,000-gallon semitrailers or 10,000-gallon tank cars. A determination would have to be made as to whether shipment of the liquid waste in tank car lots is allowable under existing ICC Regulations. The liquid would technically be a Poison, Class D, Group III, Radioactive Material (49 CFR 73.391), and as such would have to comply with the "inside container" package regulation (49 CFR 73.393). However, if it can be shown that the tank car is leakproof and that there is no external contamination or radiation shield, the shipment may be exempted from the packaging regulation (49 CFR 73.392).

In general, handling and shipping by rail of the liquid will be safer, more efficient, and more economical than handling and shipment of solid waste by any means. This is partly due to greater knowledge and more experience in handling dangerous liquids.

2.3.5 Ultimate Disposal. As shown in Section 2.3.2, between $10^7$ and $10^8$ gal/mi$^2$ of liquid waste can be generated during the decontamination effort. The fastest and most economical means of disposal would be in accordance with 10 CFR 20.303, "Disposal by Release into Sanitary Sewerage Systems," which permits release of radioactive material into a sanitary sewerage system as long as the quantity, which if diluted by the average daily quantity of sewerage released, results in an average concentration equal to or less than specified limits. For insoluble plutonium, this is $8 \times 10^{-4}$ μc/ml. By assuming no dilution factor, the maximum permissable release concentration is then 3 μc/gal or 47 μg/gal. With an average washdown of 1 gal/ft$^2$ or 10.8 gal/m$^2$, the maximum surface concentration that may be treated with no dilution is 500 μg/m$^2$. For contamination levels greater than this, the waste liquid may be diluted with liquid from a less contaminated area.

If the liquid must be disposed of at a separate disposal site, all the factors outlined in Section 2.2.5 are again applicable. At the disposal site, the liquid may be discharged into settling ditches or ponds and allowed to leach into the soil.

## 2.4 Suburban Areas and Airfields.

Suburban type land is characterized by a higher percentage of paved or improved land than rural areas, but contains more than 50 percent free land area. The improved land is in the form of streets, roads, dwellings, stores, and light industry that restricts the mobility of large earthmoving equipment. Machine operations must be done with smaller units.

An airfield or airbase will be a composite of free land, large paved areas, and structures. Although an airfield may have the same proportion of free to improved land that a suburban area has, the extent on an airbase of each type of area is very large, that is, it is not sectionalized. For this reason, large earthmoving equipment and large-scale paved area decontamination techniques can easily be used. Previous analysis of the decontamination of a typical air base by water leaching or plowing has already been done (Reference 12).

In either case, suburban area or airfield, both solid or liquid waste will be generated in direct proportion to the amount and type of surface area involved. Decontamination, collection, packaging, and transportation procedures will be similar to those outlined in Sections 2.2 and 2.3.

## 2.5 Radiological Safety Precautions.

Radiological safety procedures during the collection and packaging procedures will be similar to those outlined in TM 3-225, with the exception that there will be no external radiation hazard. Resuspension factors during the collection phase will be extremely high and use of full face masks will be mandatory. Contamination zones must be established and anticontamination clothing must be worn by personnel inside the area to prevent the spread of contamination. . If the waste is transported to a railhead and then loaded into some type of railroad car, the railhead will be designated as a contaminated area. The hauling unit may have to be decontaminated when it leaves the accident site for the railhead and decontaminated again when the unit leaves the railhead for return to the site. The railroad cars must also be decontaminated when they leave the disposal site.

In general, each place where the solid or liquid radioactive waste is openly handled will become a contaminated area and proper radiological precautions must be taken. Continuous air samples and routine swipe samples will be collected in each contaminated area to determine the actual hazard; frequent surveys of each area will be made to determine that no spread of contamination occurs. These requirements emphasize the concept of collecting and packaging the waste as early as possible in the disposal cycle. If the packaging can be accomplished early enough to eliminate one or more contaminated transfer points, the cleanup operation will be greatly improved.

If it is necessary to move the waste through noncontaminated areas (rail shipment, highway rights-of-way, etc.) precautions and surveys must be made to ensure that there is no spillage enroute. In addition, appropriate packaging regulations will be followed unless waivers to the provisions of 49 CFR are obtained.

## 3. ECONOMICS

### 3.1 General.

Because of the wide variety of parameters applicable to any given accident situation, it would be impractical to give a completely detailed economic analysis of a nuclear-weapon accident. The following study is based on very broad assumptions and generalizations that can easily cause order-of-magnitude errors in economic analysis.

In general, the costs are estimated according to standard practices of time and equipment utilization (Reference 24). Such cost factors vary with different areas and situations, equipment costs varying with current changes in purchase costs, and availability of such equipment. As a conservative factor, total costs have been raised an arbitrary 20 percent to compensate for increased costs and decreased utilization due to the radiological situation. This is independent of the cost of maintaining decontamination stations and conducting operational surveys.

The total economic cost is calculated as follows:

(1) The operation is broken down into component parts and each subunit is analyzed independently.

(2) For each suboperation, the manpower and equipment time needed to perform each job is computed.

(3) The total equipment and manpower time for each unit is multiplied by the unit time cost factor and summed for each unit to obtain total. The 20-percent compensation factor is then added.

(4) The reclamation cost of the square mile or square yard of affected area involved is calculated. A linear cost per area relationship is assumed.

It should be noted that there are no replacement costs calculated, no land value usage costs and no litigation costs estimated. These factors are beyond the scope of this study and will not even be estimated.

### 3.2 Free Land, Open.

Free land, open, is defined as unimproved land, covered only with undergrowth and shrubbery, and large enough for use of full-scale earthmoving equipment. Economic costs will be estimated as to whether the waste disposal efforts are minimum, large, or maximum.

Minimum Effort - Minimum waste disposal effort of this type will be as follows: Heavy underbrush and very light trees are pushed to the side of the contaminated area where they are shallow-buried and covered with uncontaminated topsoil; the stripped area is then plowed under by deep plowing. Small objects such as fences are buried and any other structures are washed down. The cost of such an operation would be, as shown in Table 3.1, at least $80,000 per square mile or $0.03 per square yard of affected area. Notice that over 75 percent of this cost is the stripping operations. Absence of heavy brush will correspondingly decrease this cost figure, while presence of trees or woodlands will increase the cost figure.

Large Effort - A large-scale waste disposal effort is described as clearing the land and then removing 3 inches of topsoil and transporting it 30 miles to a site for burial. Collection will be made by 18 cubic yard wheel-type scrapers or by loading trucks or dump wagons with a power shovel. A decontamination station will be set up at the accident site and at disposal sites to decontaminate the vehicle as it leaves each area. Prior to leaving the accident site, the land will be fixed by spraying with road oil. For this estimate, the volume of brush, undergrowth, debris, etc.,

TABLE 3.1 COST PER SQUARE MILE OF MINIMUM WASTE DISPOSAL EFFORT, FREE LAND - OPEN

| Operation | Man Hours | Equipment Hours | Cost |
|---|---|---|---|
| 1-Clearing Grubbing, & Stripping | 8,850 ($31,000) | 8,850 ($32,000) | $63,000 |
| 2-Plowing | 1,100 ($4,000) | 1,100 ($5,000) | $ 9,000 |
| 3-Radiological Safety | 800 ($8,000) | | $ 8,000 |
| Total | 10,750 | 9,950 | $80,000 ($0.03 per square yard) |

is added to the soil volume to obtain a working figure of $5x10^5$ $yd^3/mi^2$. Table 3.2 gives the economic costs for this effort. As shown, the cost varies from $0.20 to about $0.40 per square yard or approximately 10 times the cost of plowing under. The major cost is reflected in both the transportation and radiological safety costs. Shortening the haul distances and haul times will proportionately reduce the transportation costs while use of large bulk hauling equipment or Army equipment and personnel will reduce the labor and equipment costs.

Maximum Effort - In the maximum effort, the soil is picked up, carried 3 miles to the railhead, and shipped 100 miles by rail to a military installation for burial. The cost breakdown between bulk handling and conex shipment is shown in Table 3.3.

The transportation costs are the same for either conex containers or hopper cars since carload rates apply for both. These appear at first glance to be exessive; radioactive debris is considered by common carriers to be a dangerous material and the freight rates are almost double those for hauling ordinary soil or sand. However, for the movement of 7100 carloads per square mile (142 trains of 50 cars), it may be possible to negotiate a significant freight rate reduction if the true radiological hazard is established, and unit trains are used.

TABLE 3.2 COST PER SQUARE MILE OF LARGE WASTE DISPOSAL EFFORT, FREE LAND-OPEN, FOR THREE TYPES OF HAULING EQUIPMENT

| Operation | Man-Hours | Equipment Hours | Cost |
|---|---|---|---|
| 1. Clearing, Grubbing | 4,600 ($16,000) | 4,600 ($17,000) | $ 33,000 |
| 2. Stripping | 1,700 ($6,000) | 1,700 ($9,000) | $ 15,000 |
| 3. Casting | 3,000 ($10,000) | 3,000 ($11,000) | $ 21,000 |
| 4. Haul w/18 yd scraper | 100,000 ($350,000) | 100,000 ($500,000) | $ 850,000 |
| 5. Haul w/trucks (5 ton) | 240,000 ($480,000) | 240,000 ($600,000) | $1,080,000 |
| 6. Haul w/dump wagons (18 yd) | 67,000 ($170,000) | 67,000 ($240,000) | $ 410,000 |
| 7. Burial Site Excavating and Filling | 6,400 ($22,000) | 6,400 ($23,000) | $ 45,000 |
| 8. Radiological Safety | 20,000 ($100,000) | | $ 100,000 |
| Total for Hauling w/Scrapers (Operations 1,2,4,7,8) | 132,700 | 112,700 | $1,043,000 ($0.34 per square yard) |
| Total for Hauling w/Trucks (Operations 1,2,3,5,7,8) | 275,700 | 255,700 | $1,294,000 ($0.42 per square yard) |
| Total for Hauling w/Dump Wagons (Operations 1,2,3,6,7,8) | 102,700 | 82,700 | $624,000 ($0.20 per square yard) |

### 3.3 Free Land - Wooded.

Wooded areas will greatly increase the magnitude and economics of the problem; an average wooded area will increase waste volume by 50 to 100 percent and more than triple the reclamation time because of the bulkiness and difficulties of handling the trees. Of course, the standard construction method of burning the wood will be inadmissable because of the radiological situation. Cost per unit area will be increased by an order-of-magnitude.

### 3.4 Paved Areas.

As noted in Section 2.3.5, paved areas present no waste disposal problems if enough water is used to satisfy the criteria of 10 CFR 20; the only waste disposal cost will be water, labor, and pumping or distributing equipment. Rates given in TM 3-225 are sufficient to give dilution and economic costs and are detailed in Table 3.4. Notice that the cost range is an order-of-magnitude less than costs of solid disposal. If the liquid waste has to be physically picked up and transported, the cost will rapidly approach that of a large land disposal effort.

TABLE 3.4 COST PER SQUARE MILE OF DECONTAMINATION OF HARD SURFACES

| Operation | Man-Hours | Equipment Hours | Cost |
|---|---|---|---|
| 1. Motorized Flushing of Paved Areas | 1,540 ($4,600) | 770 ($2,000) | $ 6,600 |
| a- Water | | | $ 2,800 |
| b- Radiological Safety | 770 ($3,800) | | $ 3,800 |
| | | Total | $13,200 ($0.004 per square yard) |
| 2. Firehose Paved Areas | 11,100 ($35,500) | 2,220 (Hoses only) | $35,500 |
| a- Water | | | $ 2,800 |
| b- Radiological Safety | 2,220 ($11,100) | | $11,100 |
| | | Total | $49,400 ($0.016 per square yard) |
| 3. Firehose Structures | 13,900 ($44,500) | 2,780 (Hoses only) | $44,500 |
| a- Water | | | $ 2,800 |
| b- Radiological Safety | 2,780 ($13,900) | | $13,900 |
| | | Total | $61,200 ($0.02 per square yard) |

TABLE 3.3 COST PER SQUARE MILE OF MAXIMUM WASTE DISPOSAL EFFORT, FREE LAND-OPEN, FOR TWO TYPES OF SHIPMENT

| Operation | Man-Hours | Equipment Hours | Cost |
|---|---|---|---|
| 1. Clearing, Grubbing | 4,600 ($16,000) | 4,600 ($17,000) | $ 33,000 |
| 2. Stripping & Hauling | 13,400 ($47,000) | 13,400 ($67,000) | $ 114,000 |
| 3. Transfer - Conex | 100,000 ($275,000) | 50,000 ($90,000) | $ 365,000 |
| 4. Transfer - Hopper Car | 9,900 ($30,000) | 3,300 ($12,000) | $ 42,000 |
| 5. Transfer Sites Construction | 5,000 ($18,000) | 5,000 ($18,000) | $ 36,000 |
| 6. Transportation | | | $7,000,000 |
| 7. Burial Site Excavation & Back-filling | 6,400 ($22,000) | 6,400 ($23,000) | $ 45,000 |
| 8. Radiological Safety | 27,000 ($135,000) | | $ 135,000 |
| Total for Conex Shipment (Operations 1,2, 3,5,6,7,8) | 156,400 | 79,400 | $7,728,000 ($2.50 per square yard) |
| Total for Hopper Car Shipment (Operations 1,2,4,5,6,7,8) | 66,300 | 32,700 | $7,405,000 ($2.40 per square yard) |

## 4. AVAILABLE RESOURCES

### 4.1 Earthmoving.

All of the vast earthmoving resources available to the Army are contained in the various engineering units and to list all of them at this time would be ponderous. Detailed characteristics and specifications are listed in the various Tables of Organization and field and technical manuals (References 18 through 22). In brief, the most appropriate type of unit to employ is the Engineering Construction Battalion (TOE 5-115) consisting of a Headquarters and Headquarters Company, one Engineer Equipment Maintenance Company, and three Construction Companies. This battalion is capable of producing 100,000 man hours of construction effort per month on a sustained two-shift basis at full strength and is capable of any large-scale earthmoving operation. Major pieces of earthmoving equipment are: crane shovels, ditching machines, scoop loaders, dump trucks, 18 cubic yard scrapers, full tracked and rubber tired tractors with dozer blades, graders, and water distributors.

For additional earth hauling, the Engineer Dump Truck Company (TOE 5-124), consisting of two platoons of twenty-four trucks each, is capable of moving 240 cubic yards of material per round trip. This capability may be augmented by use of additional dump trucks. Examination of requirements in Tables 3.1, 3.2, and 3.3 indicates that the Engineering Construction Battalion and the Engineer Dump Truck Company, augmented by extra dump trucks, are capable of reclaiming a square mile of contaminated land within 1 to 6 weeks. The Army also has the capability of moving material through Government-owned rail transportation, as shown in Table 4.1.

TABLE 4.1 DOD AND AEC RAILROAD ROLLING STOCK

| Type | Number | Capability | Dimensions | Identification |
|---|---|---|---|---|
| Box | 876 | 100,000 lb | 50'x9'3"x10' | USNX - NAVY |
| Box | 100 | 100,000 lb | 40'x9'2"x10'6" | USAX - ARMY |
| Tank | 3356 | 10,000 gal | N/A | USAX - ARMY |
| Flat | 900 | 200,000 lb | 54'x10' | USAX - ARMY |
| Hopper (Covered) | 83 | 3120 $ft^3$ | N/A | ATMX - AEC |
| Hopper (Covered) | 14 | 4275 ft | N/A | ATMX - AEC |

The box cars could not be used for transporting radioactive waste because the extra effort necessary to seal the waste inside the car would make this method of shipment unfeasible.

In addition, the joint services possess nearly 100,000 conex transportainers scattered throughout the free world and it is reasonable to assume that the depot stockpile of 10 percent or 10,000 transportainers could be made available in the event that closed-container transportation is needed.

### 4.2 Disposal.

There are sufficient Army installations to ensure that disposal sites will be available; however, selection of the best disposal site will depend upon the amount of free land available, depth of the water table, soil characteristics, and economic features.

## 5. CONCLUSIONS

As a result of this study, the following conclusions, based on available experimental data, are made:

The land area contaminated to a significant extent (100 $\mu g/m^2$) due to a nuclear-weapon accident may be a maximum of 0.5 $mi^2$. This area could extend to 2.5 $mi^2$ if decontamination were required to the 10 $\mu g/m^2$ contour.

It is both economically and radiologically more practicable to plow under the contaminated soil and to wash down the contaminated paved areas with a minimum of waste disposal.

If it were necessary to decontaminate the area by removal of the contaminate to a disposal site:

1. The approximate magnitude of waste generated would be:

   Soil: $5 \times 10^5$ $yd^3/mi^2$

   Liquid: $10^7$ to $10^8$ $gal/mi^2$

2. An Engineering Construction Battalion, augmented by an Engineering Dump Truck Company with extra equipment, could reclaim the affected area in 1 to 6 weeks.

3. The Army and DOD have sufficient transportation resources to transport the waste.

4. The Army has sufficient land to provide a disposal site.

5. The cost of reclamation and waste disposal, based on equipment and labor costs, may vary from 0.08 to 7.8 million dollars, or more, per square mile of affected land.

## 6. RECOMMENDATIONS

### 6.1 General.

It should be recognized and re-emphasized that this study has been only a first approximation to a very complex and difficult problem and that a great deal of additional work must be done in order to completely evaluate it. Two of the more complex areas that need to be further analyzed are packaging and disposal.

### 6.2 Packaging.

Studies should be made in bulk packaging of soils with emphasis on radiological safety. The dusty conditions normally incident to bulk earthmoving operations must be suppressed. The ability of a road oil or water spray to inhibit resuspension during vehicular movement should be studied. Prototype protective covers should be designed for scrapers, dump trucks, and dump wagons. These covers should be either canvas or sheet metal, be easily installed, removed, and decontaminated, and should be extensively tested to determine the degree of radiological safety afforded under various conditions. The conex container should be extensively tested to verify that it can safely carry a 10-ton load of soil without failure. Expedient methods of reinforcement and sealing of the door areas to preclude content leakage should be determined.

### 6.3 Disposal.

A survey of Army installations should be made to determine and document those sites suitable for emergency disposal of bulk radioactive waste. All suitable installations should be so designated and appropriate contingency plans developed.

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Procedures for decontamination, collection, packaging, transportation and ultimate disposal of the large quantities of radioactive waste generated as a result of a nuclear-weapon accident are presented. Plutonium hazard and dispersion, previous research on nuclear-weapon accident hazards, as well as acceptable levels of contamination are reviewed and discussed. From Test Group 57 and Roller Coaster data, the extent of the significantly contaminated area was estimated to be between 0.1 and 0.5 $mi^2$.

Types of waste generated and methods of collecting, packaging and transporting are presented for rural, industrial, suburban, and airfield areas. Only first approximations of economic costs are made for reclamation of each type of area. Social and legal costs are not estimated. The equipment for cleanup available to the Army through organic units and through Government agencies is reviewed.

It is concluded that, while the Army theoretically has sufficient resources to conduct a cleanup of an accident site, further study is needed to determine pre-planned procedures, optimum utilization of available equipment, and expedient packaging procedures.

| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
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